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THESIS

IMPROVING TEST THROUGHPUT ON A NAVY OPEN-AIR TEST AND EVALUATION RANGE

by

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September 2008

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13. ABSTRACT (maximum 200 words)

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The effort involved evaluating range usage, identifying obstacles to increased throughput, and evaluating the processes associated with the obstacles. Recommendations for process changes were made and applied to a set of historical data to determine the impact of the processes and compare them with the historical solution. Data from the analysis show that specific changes to current processes have the potential to increase throughput by 9% without the need for additional resources.

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IMPROVING TEST THROUGHPUT ON A NAVY OPEN-AIR TEST AND EVALUATION RANGE

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Naval Air Systems Command's (NAVAIRs) weapons test ranges at China Lake, CA struggle to meet increasing demand. Development programs are bringing more complex and capable weapons to the ranges. The resources of the ranges are being stretched thin and not all requests for testing are accommodated. The purpose of this paper is to seek a solution to increase range throughput within the constraints of the current resources.

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LIST OF ACRONYMS AND ABBREVIATIONS

NOTS	Naval Ordnance Test Station
T&E	Test and Evaluation
R&D	Research and Development
NAVAIR	Naval Air Systems Command
EW	Electronic Warfare
DT	Developmental Testing
OT	Operational Testing
COMOPTEVFOR	Commander Operational Test and Evaluation Force
TEMP	Test and Evaluation Master Plan
GPS	Global Positioning System
TSPI	Time Space Position Information
KTM	Kineto Tracking Mount
TRMS	Test Resource Management System
MOE	Measure of Effectiveness

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EXECUTIVE SUMMARY

NAVAIR's ranges are national assets. The investment in infrastructure, instrumentation, and other resources is significant and the amount of land set aside for testing cannot be duplicated. Department of Defense weapons acquisition programs are dependent on ranges to perform testing in support of acquisition decisions. It is critical that ranges be managed to provide the greatest possible throughput to meet increasing demands.

This study at NAVAIR's China Lake ranges demonstrates how additional capacity can result from applying systems engineering principles. Analysis indicates processes can be changed to encourage less frequent movement of instrumentation assets. Fewer moves equates to less setup time, less wear and tear on instrumentation systems, and more time for testing. Choosing to accept the recommendations of this paper will provide new focus on meeting increasing customer requirements by working more efficiently with the resources currently available. Initial analysis indicates that an increase of 9% in available range time can be obtained at no cost by using these recommendations.

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I. INTRODUCTION

A. BACKGROUND

Open-air weapons ranges were established at China Lake, California, as part of the establishment of the Naval Ordnance Test Station (NOTS) in 1943 to support Test and Evaluation (T&E) of rockets and aviation ordnance. For the past 65 years these ranges have supported weapons Research and Development (R&D) programs for the Navy as well as other US defense services, defense agencies, allied forces, and private industry. Access to instrumented test ranges with appropriate infrastructure, resources, and availability is essential to obtaining "decision quality data" in support of programmatic decisions.

The China Lake ranges are managed by the Range Department of the Naval Air Systems Command (NAVAIR) and comprise over 1,700 square miles of land and 20,000 square miles of controlled airspace. The ranges carry out testing on a wide variety of systems and components across the entire spectrum of military systems. The increasing complexity of weapons systems brings a need for an equally complex test environment. There is a continuing trend to increase the distance weapons are able to travel after launch or release. Testing such systems requires larger portions of the range, or even the combined resources of several ranges, to perform adequate tests. These range challenges are compounded by years of forced manpower downsizing and reduced budgets. Although the ranges conduct hundreds of test operations per month, they are not able to accommodate all requests for testing with existing resources using the current processes.

B. PURPOSE

The purpose of this thesis is to analyze range processes, identify factors that restrict throughput, and propose modifications to processes that will result in additional available time for testing.

C. RESEARCH QUESTION

Can the range throughput be increased by analyzing existing processes and applying system engineering principles to modify those processes?

D. BENEFITS OF STUDY

The thesis will provide recommendations for process changes to improve utilization of range time and other range resources. Impact of suggested changes on shareholders and on other processes will be identified to provide decision makers all the data needed for a decision on implementing the changes. The range will benefit from the study by being presented options for improved utilization.

E. SCOPE AND METHODOLOGY

This thesis focuses on the China Lake Range complex of NAVAIR's Ranges Department. While policy and resource issues are increasingly common with the Electronic Combat Range on the southern portions of the same station, there is no attempt to include Electronic Warfare (EW) testing in this analysis. The missions, test resources, and scenario designs are different enough that EW throughput issues should be addressed independently.

Analysis was performed on processes, historical scheduling data, and on information provided in interviews with personnel of the range department and with range customers. The scope of policies and processes analyzed is limited to those under control of the range department (NAVAIR 5.2). Increasing hours of operations, manpower, and number of range support systems is outside the scope of this study.

The range is committed to getting as many programs on the schedule as possible, but program priorities must be taken into account. It is not within the scope of this study to disregard relative program priority or to seek improvement by excluding part of the current customer base in favor of another.

II. BACKGROUND RESEARCH

A. INTRODUCTION

The information in this chapter is intended to present enough detail about range operations and range processes to provide a foundation for understanding the information presented in the rest of the paper. The range is a large and complex system with many interrelated components and significant external inputs. There is no attempt to put forth complete details on any portion of the range system. Emphasis is placed on the internal processes and interactions that are within the influence of the Range Department that will receive the recommendations contained in this thesis.

B. CUSTOMER REQUIREMENTS PROCESS

The Test Management Branch, Code 52130MD, is the designated entry point for customers who need to test on the ranges. Customers are directed to Test Management by range literature, presentations, web-sites, and by word of mouth. The test manager assigned to a program is responsible for learning the customers' requirements well enough to determine the feasibility of conducting testing on the ranges. Once feasibility has been established the test manager works with all involved parties to use the test requirements of the program to design specific test events. These test events are designed and conducted so that the resulting data meet the requirements for customers to evaluate the performance of their item under test.

Acquisition programs following the standard cycle will have several phases of testing. Developmental Testing (DT) is under the control of the responsible organization. This organization may be within the government or it may be a contractor. Developmental test programs have a high degree of requirements variability from test to test as they verify design concepts and cycle through test-fix-test. After the program enters Operational Test (OT) there is a much more formal process for the testing and for validation of test requirements. In OT the responsible test organization, such as Commander Operational Test and Evaluation Force (COMOPTEVFOR) for the Navy,

will have written a Test and Evaluation Master Plan (TEMP) that clearly defines key performance parameters. This plan is signed by the tester but also by the services' executive agent for testing. The executive agent for Navy testing is N091. A program TEMP will define test objectives and the plan and schedule for meeting the objectives. The program's test engineer works with the ranges to determine the details of the test design and how range resources will support the test.

Some customers have extensive experience on test ranges and bring well developed test plans with clear requirements tied to specific test objectives. New programs, or those with less experienced test teams, may need coaching and interaction with the test manager and other range support personnel experienced in test design. Requirements established during early customer contact become design constraints, as they drive all aspects of test scenario design and conduct. The event plans must also ensure tests are conducted within the bounds of range policy with regards to safe conduct and regulatory compliance.

Test managers are guided by a Test Managers Processes handbook (Test Management Processes, 2007). The book is a collection of instructions, guidance, policy, and procedures. New documents and updates to existing documents are added as needed. Within the handbook are flow charts, forms, and checklists that guide the requirements collection process.

Test event design is a product of customer requirements and considerations required for safe test conduct. Customer test parameters drive decisions on instrumentation requirements. Factors that drive test design decisions determine test constraints. Examples of program requirements that drive test design are:

- Test objectives, including measurement details such as units, accuracy, and resolution
- Key performance parameters
- Other details contained in program documentation such as a TEMP

C. CURRENT PROCESS FOR DETERMINING RANGE RESOURCE REQUIREMENTS

Establishing range resource requirements for an event requires the interaction of a team of experienced resource providers. The Range Department has several divisions which provide resources in support of testing. Each division has staff to assist in assessing proper test design and test conduct. Resources provided or controlled within the range divisions include:

- Air operations support (Airspace Controllers)
- Airspace surveillance
- Range access control
- Ground test conductors
- Range land space
- Range airspace
- Communications support
    - Radios
    - Land lines
    - Access to range and off-range digital network for video, audio, and other sensor data transport
- Computer operations
- Fixed video: 6 options
- Tracking cameras: 4 options
- Frequency spectrum monitoring
- Generators
- Global Positioning System (GPS) air and ground systems
- Radar tracking and radar directed video support: 15 options
- Ground laser and spot video support
- Telemetry systems: 17 options
- Range cleanup
- Scoring support
- Ground-based stationary targets

- Air vehicle instrumentation
- Weapons instrumentation
- Weather data (pre-test and real-time if needed)

Additional resources outside the range department that require coordination include:

- Moving and airborne targets
- Aircraft
- Airfield access
- Ordnance handling and tracking

A detailed test design will determine the number and mix of resources required. An example is the requirement for providing Time Space Position Information (TSPI) of an item dropped from an aircraft. Both radar (Figure 1) and Kineto Tracking Mounts (KTMs) (Figure 2) can be used to obtain TSPI depending on the required accuracy. The radar solution uses one or more of several radar systems at fixed locations on the range to obtain TSPI. Setup time for the radar is less than 30 minutes. The KTMs can collect calibrated video data for processing that will yield higher precision TSPI, but with added cost in resources and time. KTMs are mobile systems that are transported to the test location and then require a two-hour calibration time. The processing of the KTM data to yield TSPI requires manual processing of each frame of image data and uses triangulation to determine precise location. Processing takes hours for each minute of test data. Since triangulation is used, a TSPI solution requires multiple KTMs with complimentary views of the test item. Once again, the difference between a simple radar solution and a complex KTM solution is traced back to required resolution accuracy. An overstatement of requirements can result in unneeded setup time, expensive data products, and significantly longer time to provide a data product.

Figure 1. This remotely operated tracking radar is an example of an instrumentation resource that is at a fixed location and cannot be moved.

Figure 2. One of 15 Kineto Tracking Mounts (KTMs) with instrumentation cameras. KTM systems are mounted on trailers and towed from one location to another as needed.

Determination of required number and location of KTMs is itself an engineering challenge. The range supports 12 mobile KTMs that can be located at any combination of over 200 surveyed KTM pads on the range. Geometry of the planned target path with relation to the other KTM locations determines achievable accuracy. An experienced instrumentation team determines the required setup based on the requirements presented by the test manager.

Fixed video systems are often deployed in close proximity to ground targets to provide documentation of weapon impact. These systems are remotely operated because

they are inside the hazard areas. The requirement for “still” video instrumentation requires precise placement and positioning of remotely operated cameras at individually surveyed locations as shown in Figure 3. Customer requirements drive the number of cameras and geometry of the camera placement. When the mission is to record a weapon engagement with a moving target, the camera setup must include the entire area of the motion of the target during the critical portions of the test event. This added complexity can require up to 20 cameras and increase the setup time to an entire workday.

Figure 3. Fixed video camera and support equipment placed to instrument a test.

Some laser support capability exists within the range’s Instrumentation Division, but most tests require support from outside the Range Department. The setup for laser support is also complex and time consuming. The lookdown angle of the required equipment requires camera placement on towers as shown in Figure 4. The specifics of the test will determine which type of tower can be used. Nearly all applications rely on mobile towers that must be transported and erected before they can be used.

Figure 4. Laser support van and two towers used to support laser scoring instrumentation. Note the mobile tower and base.

There are limited numbers of GPS, telemetry, and radar systems at the range. Most of these resources are at fixed locations. Requirements for these resources are determined by required bandwidth, frequency de-confliction, and the geometry and ground topology to ensure line of sight between the resource and the item under test. These resources must be scheduled based on test priority. For many of these systems it is not possible to increase capacity by purchasing additional systems as the availability and allocation of frequency spectrum is a limiting factor.

Chapter IV will further address which of these resources are key constraints and how that is determined.

D. CURRENT SCHEDULING PROCESS

All events conducted on the Land Ranges are scheduled through the Land Range Test Management Branch Scheduling Office. The schedule of range test events for a given week is locked in and published on Wednesday of the prior week. Before being considered for a slot on the range schedule, the detailed event plan must be approved by multiple range support offices including: finance, test management, test operations, range data systems, frequency management, laser safety, range safety, the environmental office,

and explosive ordnance. Inputs to the scheduling process are in the form of electronic submissions using a local tool (the Test Resource Management System (TRMS)) and include:

- Requested date and time for the event with alternative dates and times, if any
- Aircraft schedule from the squadrons supporting testing (some come with priority rankings)
- Event plan containing
    - Target description and location
    - Range area required for conduct
    - Test bay requirements
    - Telemetry requirements
    - Radar support requirements
    - Requirements for still video, tracking video, and laser setup
    - Weapons to be used
    - Use of laser, jamming, or other emissions
    - Map with event data such as captive carry routes, run-in headings, release point, target locations, and safety footprints
    - Required evacuation and road closure details

Each Wednesday the scheduling office personnel take the inputs provided above and begin the process of building the next week's schedule. Day by day they consider the requested tests and attempt to fit as many as possible onto the schedule. There are priority considerations provided by the local test wing as well as by the test management branch head who has the final say on scheduling.

The variability associated with a wide variety of test complexity adds significant challenges to the scheduling process. Video instrumentation setup time is an hour for some tests and 6 to 8 hours for other tests. Instrumentation crews can work safely under some ongoing tests in preparation for the next test, but must evacuate to safe locations during others. Setup time for test bays can be 30 minutes or 60 minutes depending on test specifics. Some tests can run concurrently on different portions of the range if adequate supporting resources are available. At times the same portion of the range can

be used by two testers with appropriate altitude buffers. The scheduling office spends a great deal of time on scheduling day on the phone with test managers and various resource providers to find areas where constraints can be relaxed to allow better range utilization and to insure all tests scheduled have the required resources and approvals.

The schedulers work to have a viable draft schedule approved by the branch head and ready for the weekly scheduling meeting that takes place at 2:30 pm every Wednesday. Frequency management, test controllers, air controllers, test managers, and resource providers attend the scheduling meeting. The schedule is discussed in detail with opportunities for input from participants on issues that may still need further evaluation to avoid conflicts. It is common for one or more events to have changes made in the meeting or shortly thereafter based on inputs from the meeting. After the meeting the schedule is updated to reflect necessary changes. The schedule is reviewed and approved by the branch head a final time and the schedule is locked in no later than 9:00 am on Thursday.

E. CHAPTER SUMMARY

Information has been presented to demonstrate the complexity of the range and provide a frame of reference for the analysis that will be presented. The validation of test objectives and test setup has been discussed. There are complex interactions among the various parts of the range and there are real test consequences in cost and schedule impact for choices made along the way.

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III. APPLICATION OF STUDY

A. INTRODUCTION

In this chapter the analysis of the range system will begin with a discussion of interfaces and decision points. The role of a range software tool in the process will be put in context, and historic test data from a four week period will be selected as a baseline against which proposed changes will be measured. Lastly the measure of effectiveness for assessing results will be defined.

B. PROCESS INTERFACES AND DECISION POINTS

There are many interfaces and decision points in the test planning and execution processes. It is convenient to look at the interfaces and decision points chronologically in five phases.

1. Phase 1 – Early Customer Contact

The first interface is between the potential customer and a test manager. In this interface, the customer provides enough detail about the program's test objectives and required conditions to allow the test manager to determine the feasibility of conducting the test on the range. If a program requests conditions or resources beyond typical range capability, further discussions will need to occur between the customer and range engineering staff to determine if the requested test can be accommodated.

2. Phase 2 – Event Planning

Event planning, the most time consuming part of the process, is the second phase and involves the most decision points. In this phase, the test manager uses the customer's test plan as a starting point to make a series of decisions that results in a detailed event plan. Each event plan supports a test scenario, or set of scenarios, that measure the item's performance against the documented program objectives. Decisions are made on upper level requirements for instrumentation support. The interface at this level is typically

between the test manager and the customer. Upper level decisions would include items such as the need for TSPI data and the associated accuracy, video documentation showing a particular aspect of the test item or delivery vehicle, or a telemetry link and display to show weapons status before and after launch.

Within this same event planning phase decisions must be made at the next level of complexity. These decisions define the specific test setup to meet requirements decided on at the upper level. An example would be the exact number and placement of cameras to capture the image of the test item at a precise time in the test event. This includes flight path, release time, and release condition decisions. The interfaces at this decision step include test management and all involved resource providers as well as the customer when needed.

The conclusion of the event planning phase is achieved when all approvals required to achieve "ready to conduct" status have been obtained. Each approval is a decision point. Only after all approvals have been obtained is a test considered for scheduling.

3. Phase 3 – Test Scheduling

Decisions in this phase are date, time, and location of test event. Supporting aircraft and each range resource to be used are also determined. Interfaces are through test managers to the customers and through test managers and the schedulers to each supporting resource provider. Final decision for scheduling of test events resides with the head of the test management branch.

4. Phase 4 – Test Conduct

In the test conduct phase, the test conductor from the Range Operations Division conducts the test event according to the event plan. The test conductor is the decision maker during an event. Nearly all airborne events are conducted from one or more test bays in the Range Control Center. The test bay is set up with displays from the various supporting instrumentation resources which allow the test conductor and customer real-time feedback on the item under test, the supporting resources, and the test environment.

Customers work with the test conductor to work through the planned event. If portions need to be repeated, skipped, or modified within the approved parameters of the event, it is the test conductor that makes that decision. All participants have the ability to terminate the event for reasons of safety if they perceive an unsafe situation exists. Interfaces in this phase include verbal communications within the bay, electronic voice communications within the bay and with test participants across the range, and communications with air controllers at the range and within the larger test complex.

5. Phase 5 – Data Production and Delivery

The required data product defined by the customer in planning and documented in the event plan determines what data are collected and how they are processed during and after the test. All customer deliverable products pass through a quality check to ensure correct processing. While many post-test data products are specified prior to the test as part of the event plan, it is possible for some additional products to be requested if the instrumentation and collected data support that product. All requests for test data products are made by customers through the test manager. Interfaces include the customer, test manager, and personnel in the Range Data Systems Division.

The information on interfaces and decision points is summarized in Table 1.

Phase	Interfaces	Decision Points
1. Early Customer Contact	Customer and Test Manager	Feasibility of test
2. Event Planning	Customer and Test Manager Test Manager, Resource Providers, and Customer Test Manager, Test Approvers	Event Plan Approval by: Test Management Test Operations Range Data Systems Frequency Management Laser Safety Range Safety Environmental Office Explosive Ordnance
3. Test Scheduling	Scheduling Office, Test Manager, Customers, Resource Providers	Scheduled Event (day, time, location, test conditions)
4. Test Conduct	Test Conductor, Customers, Resource Provider, Test Manager	Go-no-go Test conduct decisions
5. Data Production and Delivery	Data Systems Personnel, Customer, Test Manager	Correct and sufficient data

Table 1. Summary of interfaces and decision points in the life cycle of a test program.

6. Role of TRMS in Interfaces and Decision Tracking

Since its development, the TRMS system has become a living repository for the details of the event plan. TRMS is accessible by all test resource providers and is intended to be used as an interface to distribute and coordinate details of test plans. TRMS does not replace the face-to-face interactions that form the primary interfaces between test participants, but it does serve as an automated tool for soliciting and recording decisions in the form of approvals from the various individuals with range decision authority prior to the conduct of a test.

C. SELECTION OF REPRESENTATIVE TEST PERIOD FROM HISTORICAL DATA

Historical data archived in the scheduling office provides much of the data needed for analysis required in this report. There is variability in workload at the ranges. In periods of lighter workload less annotation exists in the records and time spacing between events is more difficult to attribute to a specific cause. The scheduling records alone do not provide a complete picture. For example they do not show where extensive amounts of time were spent setting up instrumentation outside normal working hours. Despite the lack of such data, the scheduling records still give the most complete view available from any single source.

Criterion for selection was a period of high workload where there was more demand for range time and resources than could be provided. This ensures there was a good reason for range periods that were not used for test conduct and increases the likelihood of detailed annotation in the scheduling records. While the range workload is variable, there is also an element of periodicity. Due to the nature of funding cycles there is a fiscal year impact that has historically resulted in high demand for testing in the last few months before the end of the fiscal year. A review of the scheduling records for July, August, and September 2007 indicates August had sufficient demand as well as adequate annotation for analysis purposes. The period of August 1 to 18 was chosen as the time period for a baseline against which to test the impact of proposed changes.

D. DETERMINE MEASURES OF EFFECTIVENESS

The Measure of Effectiveness (MOE) for this study is the difference in number of range hours available for testing. In this context, the MOE is only applicable looking back at historical scheduling data and comparing them with the results of re-scheduling after applying proposed process changes to the same set of testing requests.

E. CHAPTER SUMMARY

Chapter III identified interfaces and decision points critical to relevant processes that will be used in the next phase of analysis. A period of time was chosen where sufficient historical data existed to be used as a baseline for future comparison, and an MOE was selected to be used in quantifying the results of proposed changes. The groundwork is now set to focus analysis efforts on the problem of reducing restricted range time.

IV. RESEARCH ANALYSIS

A. INTRODUCTION

The object of this chapter is to describe the process used in selecting which range processes were analyzed, which ones merited proposed changes, and what the results of the changes were when applied to the baseline period selected. Historical scheduling data are used to find potential causes of restricted range time. After the causes are identified, the processes associated with the causes are reviewed and evaluated for possible changes to reduce their contribution to restricted range periods. The suggested process changes are applied retroactively to a baseline historical period and the MOE is used to determine the effect of the changes.

B. IDENTIFY MAJOR CAUSES OF INEFFICIENT RANGE USAGE

At this stage certain assumptions are made to focus the analysis on data with the highest potential for yielding additional usable range time. The first assumption is that the amount of time scheduled for each test is appropriate. The ability to carry out all the activities required in an event plan within an acceptable amount of risk to the program is best determined by the test engineer and test manager. Test time scheduled is not analyzed for efficiency.

A second assumption is that activities supporting test events take precedence over non-test-support activities. As a result, non-test-support activities do not generally compete with test events for time on the schedule. Examples of non-test-support activities include support of range infrastructure such as power distribution, and environmental stewardship activities like studies of geology, flora, fauna, insects, and animals. Since these activities are scheduled on a not-to-interfere basis, they are not analyzed for impact to range throughput.

The final assumption is that the setup time required to prepare a resource for any given test is valid and cannot be reduced. No attempt will be made in this study to

suggest that resource providers need less time to setup their respective systems in support of a test. In light of the stated assumptions, the activities that are left for analysis are those that directly support test events and require scheduling consideration, but are not performed during the actual scheduled test event time. These activities include the range's preparation for testing such as the setup of targets, instrumentation, and other activities needed for successful test conduct.

Scheduling records show every event that was scheduled as well as those requested that did not make the schedule, with annotation for the reason each was not scheduled. These records also show details such as test location and resources that were used in support of the event. Setup time can be determined from the location and list of associated resources.

Twelve weeks of historical data were used as the basis for analysis. These weeks were contiguous weeks within July, August, and September 2007. This timeframe includes the period chosen as the baseline for evaluation for the effectiveness of proposed changes.

From the resources listed previously, four were identified that require range setup time. They are KTM systems, laser systems, target preparation, and video setup. It was found that the construction and setup of targets on the range are performed around other test events and are usually completed well in advance of the required time. As such, target construction and setup do not require scheduling consideration.

The 12-week period analyzed contained 365 test events. Data for further analysis were collected only on the 97 events that required one or more of the three targeted resources. The hours required for setup of each resources was determined by the resource provider**.** The data considered are test events with associated setup time for KTM, video, or laser resources. **The impact of setup time on the range schedule is the longest time required by any one of the required resources.** The detailed data for the first week is presented in Table 2.

Date	Test #	KTM Setup Time	Video Setup Time	Laser Setup Time	Range Hours Impacted
7/3/2007	1	3	8	0	8
7/3/2007	2	0	5	0	5
7/5/2007	3	0	0	4.5	4.5
7/5/2007	4	2	0	0	2
7/6/2007	5	0	0	4.5	4.5
7/6/2007	6	3	4	0	4
Totals		**8**	**17**	**9**	**28**

Table 2. Resource setup times for the first week under analysis.

Note that the value for "range hours impacted" is only obvious by considering a single test on one row of the table. The range hours impacted can not be deduced looking at the weekly totals. A summary of the weekly totals for the entire 12 weeks is presented in Table 3.

The range is divided up into several sub-range areas to allow multiple activities to occur on the range at the same time when conditions permit. When instrumentation is set up on several sub-ranges at the same time it is possible to see large numbers for schedule hours impacted. While it is not common to have 71 range hours impacted in a week, as they were on the week ending 21 July, it does happen.

The numbers are still valid data for analysis. Each impacted range hour represents a test hour that cannot be conducted in an area of the range because setup activities are in progress. What these data do not reflect is how many of these setup activities are conducted on overtime either early in the morning for a test the same day, or late in the evening for an event the next day. Even with this overtime consideration the value of the data is not diminished. Process changes that result in less setup time will still be a relaxation of constraints that may allow improved throughput.

Week Ending (2007)	KTM Setup Hours	Video Setup Hours	Laser Setup Hours	Range Impact Hours
July 7	8	17	9	28
July 14	14	26	2	30
July 21	6	18	62	71
July 28	19	17	20	46
August 4	6	12	31	35
August 11	14	29	36	49
August 18	13	23	33	46
August 25	5	12	18	30
September 1	5	7	4	13
September 8	8	8	13	15
September 15	11	3	4	15
September 22	9	25	20	43
Totals	**118**	**196**	**225**	**424**

Table 3. Data representing 97 events and the setup time required by each resource.

The data presented in Table 3 is summarized in Figure 5. Laser Setup Time has the greatest impact on the range with Video and KTM setup respectively the second and third greatest contributors.

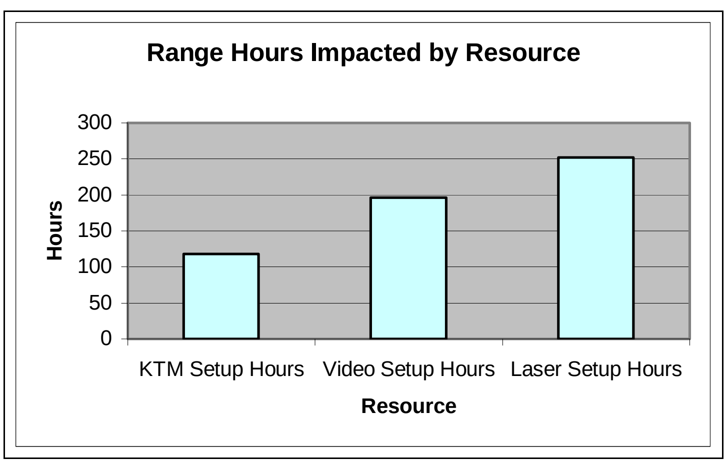

Figure 5. Range hours impacted by setup by resource type.

Further analysis of the data provides insight into the number of events that require various combinations of resources. These data are presented in Figure 6 and indicate that more events require only laser support than any other single resource or combination of resources. Laser resources have the highest impact on range time and the least correlation with other resources, making a reduction in laser setup time the most likely to have a positive impact on range time. If either of the other two resource setup times can be reduced, the change in range time impacted will still be limited by the other resource.

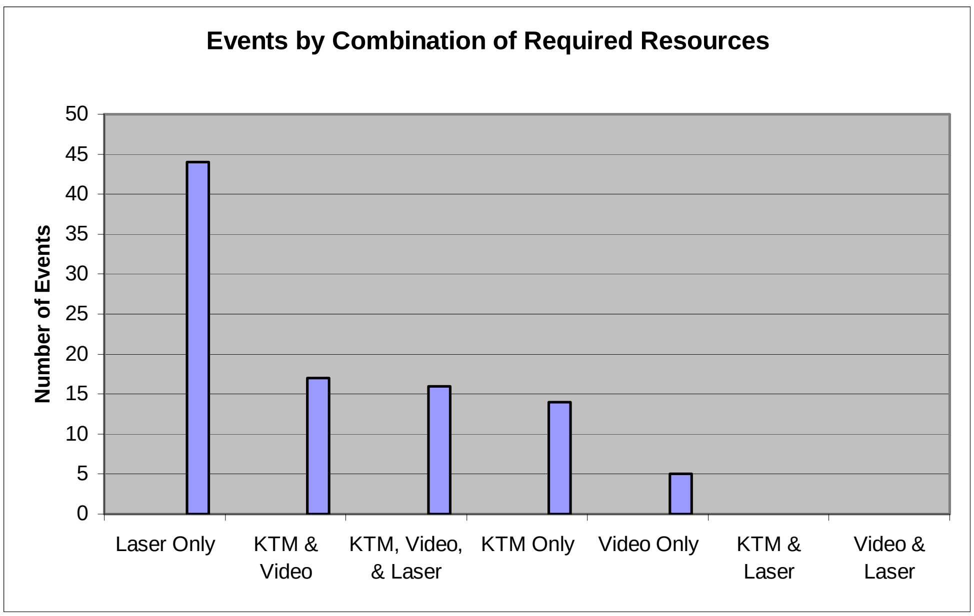

Figure 6. Test events requiring range setup by resource type.

The number of events requiring combinations of resources does not indicate which resource required the most time. The data was further analyzed to determine the correlation between setup times of each resource. Figure 7 is the result of that analysis. There is consistency in the ranking of laser setup taking the largest amount of setup time, but this analysis shows that video takes the second largest amount of range setup time. The results of this analysis were not intuitive to the author or to most of the range employees to whom it was presented. Time was spent to verify the data to the satisfaction of range management before the next step was taken. Preconceived notions about how to improve throughput were abandoned and data were allowed to lead the way. The order of priority for reducing range time impacted by setup will be on laser, video, and KTM.

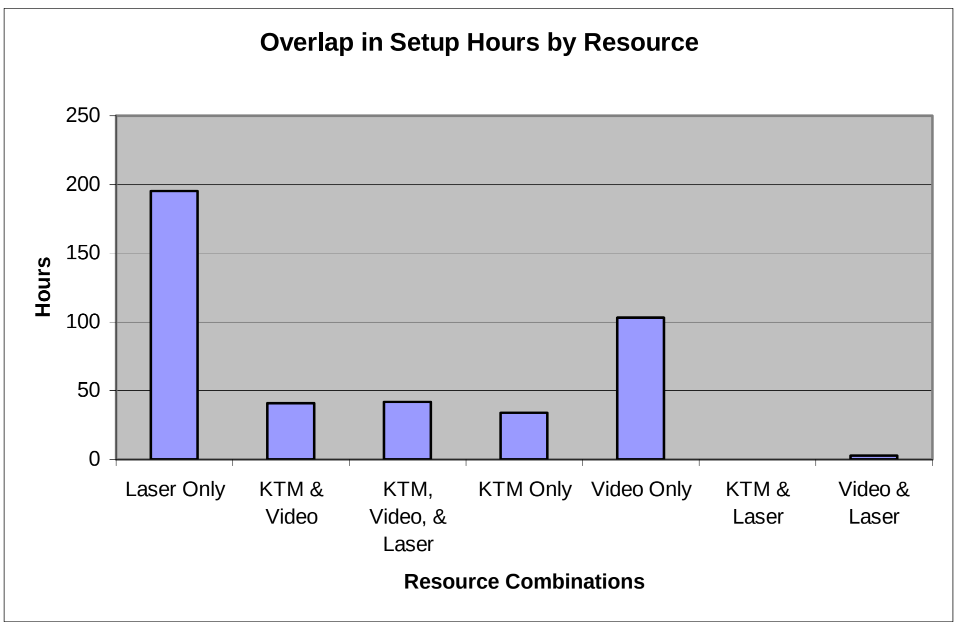

Figure 7. Setup hours by resource showing the overlap in setup time.

C. IDENTIFY PROCESSES ASSOCIATED WITH INEFFICIENT USAGE

The above analysis is used to focus on range processes that contribute to the amount of time spent on the range setting up laser, video, and KTM systems.

1. Inefficient Range Usage Resulting from the Requirements Definition Process

Some inefficiency in range usage stems from the requirements definition process. This inefficiency is caused by requirements for higher-precision instrumentation than are actually needed. Interviews show that not all test managers emphasized the need for identifying the correct required precision as they interfaced with customers. Some were satisfied with allowing the customer to use a perceived range precision standard as the default value in the requirements documentation. This practice leaves resource providers few options other than designing instrumentation schemes optimized for each individual test event with only secondary consideration for test setups that will work for multiple sequential tests. The impact of this practice is that KTM and scoring video may be required with the associated setup time, when another TSPI solution with no setup penalty, such as GPS or radar, could have been used. Even if KTMs are required, an over-statement of TSPI requirements drive the placement of KTM systems closer to the target area and increase the chance the systems will need to be moved for the next test.

2. Inefficient Range Usage Resulting from the Scheduling Process

Scheduling is performed with a view that looks primarily at test events requesting test conduct the following week. Relative priority plays a role in getting the requested time slot. These two practices reduce the opportunity to utilize a single target location and instrumentation setup for multiple test events that might be scheduled sequentially, thus reducing the setup time between events. Once again, self-imposed constraints limit a more efficient solution.

3. Inefficient Range Usage Resulting from the Instrumentation Design Process

Much of the setup time associated with preparing laser and video systems is the time required to ready the systems for transportation and then to move them from the last deployed location to the next test location, set them up, and calibrate them. The ranges cover over 1700 square miles, and thus transportation time on rough dirt roads for sensitive equipment can be significant. Data on KTM setup do not indicate as large a time requirement for transportation, but KTM setup time would benefit if transportation time is reduced. Transportation time can be reduced if the need to move from one location to another between tests is reduced.

Laser, video, and KTM system deployment locations are driven by the target location. An area of the range with many targets is Airport Lake, shown in Figure 8. The range has hundreds of target locations. Unique locations and the use of very specific targets are critical requirements for some programs. Other programs have greater flexibility in making target type and location decisions. Using a larger number of target locations increases the likelihood that instrumentation setup for a given test will require equipment relocation and calibration time. Both targets and target sites must be rebuilt after some tests. The use of too few targets sites would also be a constraint on throughput. The selection of a set of optimal targets and locations is a good topic for another study.

Figure 8. Airport Lake supports the highest concentration of weapons impact targets on the ranges.

The instrumentation design process has been hampered by higher-precision requirements than needed, as discussed previously. Analysis of the setup process and interviews with team members illuminated additional impacts. The instrumentation design process is critical. When considering placement of up to 12 mobile KTM systems, at over 200 surveyed locations on range there are 6×10^{18} combinations to choose from. An exclusion area is an area where people are not allowed during a specific test due to the potential hazards associated with the test. Some KTM sites are eliminated from consideration because they are within the exclusion area. Consideration for placement must include good geometry for data processing, as well as sun angle for the predicted test time, air quality factors that can degrade image quality as a function of distance, and geographical features that may block the item from the cameras during portions of the test.

Instrumentation design is performed by key individuals with years of experience. Using experience and intuition, setups are designed that meet most customers' requirements. The number of key individuals capable of test design is much smaller now than in the past due to downsizing and natural attrition. Due to challenges with site placement, sun angle, difficult tracking conditions, and operator proficiency, risk is

sometimes reduced by deploying more systems for a test than the minimum required. This practice may result in the inability to schedule concurrent tests that would otherwise be compatible.

D. DETERMINE PROCESS CHANGES TO IMPROVE EFFICIENCY AND IDENTIFY IMPACTS ON OTHER PROCESSES AND RESOURCE PROVIDERS

1. Proposed Changes to the Requirements Definition Process

Meaningful changes to the requirements definition process will require changes in the interface between the test manager and the customers. During this process the flexibility in test programs must be identified and used to plan test events with solutions that contribute to range efficiency. Specific areas of flexibility that will contribute to improved range efficiency include:

- Test date and time
- Target type and location
- Data precision for TSPI

One challenge will be customers who have not performed the analysis within their program to know the required precision. Customers need to be motivated to allow the range to take advantage of flexibility. Benefits for the customer include a higher likelihood of getting on the range schedule, and the potential for reduced cost associated with actual vs. inflated precision requirements.

To meet these objectives, specific process changes to the requirements definition process are recommended as follows.

Test Management Processes Handbook

- Chapter 2, Initial Requirements and Feasibility, Paragraph 2.4 – Add the following after the first sentence, "A correctly designed event plan is less restrictive and easier to schedule than one with more stringent requirements. Test managers are to get TSPI

> precision requirements from the customers and are not to select this value for the customer or suggest a value. Test managers will confer with customers who present precision requirements that seem excessive for the specific test to ensure the value is technically driven by key performance parameters of the program. The test manager will inform customers of the added cost of increasing TSPI precision requirements. Test managers should encourage customers to select commonly used target locations."

2. Proposed Changes to the Scheduling Process

The one-week view for scheduling is a self-imposed constraint that has many benefits, such as keeping the process simple, being able to ensure that the highest priority programs each week get test time, and addressing emerging requirements in the dynamic environment of Test and Evaluation. These benefits were considered as proposed changes were developed in order to try and keep as many of the benefits in place under the modified process as possible. The relative priority among customers remains the same.

The goal for the proposed changes is once again based on a relaxation of constraints to allow an improved solution. The relaxation is in two areas. The first relaxation is in considering a longer period of time in which to fit the requested tests. The second relaxation is in considering a larger number of test events to increase the likelihood of identifying events that can be conducted consecutively in the same location. Logically, the larger number of tests considered, the more that will be found to share common instrumentation requirements. Practically the solution is limited to the number of programs sharing similar instrumentation needs that are ready to test and flexible enough to take advantage of the common setup.

It only takes a few successes in matching instrumentation needs and scheduled times and locations to make a difference big enough to make range time available for another event. Success of procedure changes in scheduling depends on test managers and customers as much as on the scheduling office. Test managers need to encourage

customers to be prepared to take advantage of common instrumentation setups. Customers who have their event plans approved and some flexibility in schedule dates and times will have increased opportunity to make the schedule. This may be challenging for customers who rely on wings for aircraft assignments that are not determined far enough in advance. Additional coordination between the range, the customer, and the air wing could yield solutions to this challenge.

The information in the Test Management Process Handbook, Chapter 6, Scheduling, is not divided into paragraphs or sections, and so it is difficult to propose changes based on paragraphs. The entire section is reproduced below. Paragraph breaks have been added and the paragraphs numbered. Suggested deletions are shown in ~~strike through~~ text, and additions are *italicized*. The proposed changes to the scheduling process are as follows:

"6.1 Responsibility

All events conducted on the Land Ranges are scheduled through the Land Range Test Management Branch Scheduling offices.

6.2 Long Range Forecasting

Once test management has determined that the initial requirements and feasibility of an event are acceptable, the test manager checks the scheduling calendar for availability and initiates the scheduling process by *putting the event in the forecasting module of* ~~submitting a request for an Event schedule time through~~ the Test Resource Management System (TRMS). This initial request contains the event title with proposed dates and range times. Early submittal of these requests gives insight to test managers and supervisors as to future events and allows them to balance the workload for most efficient use of the Range. It also allows for de-conflicting events that have long lead times in preparation and planning.

6.3 Bringing the Event Plan to the Stage of Pending Schedule Approval

The test manager updates the Event schedule request as more information is collected during the Test Planning process. An approved test plan and an Event Plan with all scenario approvals are required for the request to be considered for *scheduling. As the event plan is populated with the required data and gains the needed approvals it should*

be moved from the forecasting module of TRMS to the scheduling module. ~~the following week's~~ ~~schedule~~. Event schedule requests are displayed as "Pending Scheduling Approval" on the TRMS Range Schedule as soon as they are submitted by the test manager. The deadline for submitting requests to the Scheduling office is 1000 hours each Wednesday.

6.4 Consideration of Long-Range Scheduling

At the test managers' biweekly long range forecasting meeting, test managers will present events they believe are appropriate for consideration for advance scheduling. Considerations for advance scheduling include program priority, intensive instrumentation resources, participation and coordination of non-local assets, maturity of the event plan with details and approvals, likelihood of completing all outstanding required approvals, confidence in the customers' ability to be prepared for the proposed test period, and readiness of required range assets to meet the suggested test period. After a discussion of the event with the other test managers the branch head will decide if the event will be placed on the schedule. If the decision is to schedule the event then the test manager moves it from forecasting to scheduling in TRMS. All test managers then look for other events requiring similar instrumentation capabilities that can be conducted in the same location that could take time slots prior to, or after the scheduled event. These additional events are then considered for placement on the schedule. Due to considerations for range efficiency, these programs will have looser requirements for priority than did the originally scheduled event.

6.5 The Scheduling Process

The Scheduling office uses the Event schedule requests, *events previously scheduled through the long-range scheduling process*, and aircraft schedules to prepare the daily schedules for the following week (the aircraft schedules should already have resolved frequency conflicts between the aircraft and onboard weapons or test articles. The Scheduler assigns proposed range times through prioritization, resource availability and the supervisor's discretion. The Scheduling office also confirms proposed range times for events that will use other Ranges' airspace or resources. Later on Wednesday afternoon, a review of the daily schedules for the following week is held in the Range Control Center.

Test managers, a test management supervisor and representatives from each Range resource attend the review, being attentive to resource conflicts and clarification or correction of event support requirements.

6.6 The Final Schedule

After the meeting, but no later than 0900 Thursday morning, the Scheduling office makes any required schedule adjustments, deletes the requests from TRMS that did not make the schedule, and changes the remaining events from “Pending Scheduling Approval” to “Scheduled Pending Conduct Approval,” “Scheduled Ready to Conduct,” “Standby,” or “Backup,” as appropriate. The Ready to Conduct decision is made by the Land Range Test Management and Test Operations supervisors no later than two days prior to the event. Using the Integrated Frequency Deconfliction System (IFDS), the Frequency Management Office begins identifying and resolving frequency conflicts after the Final Schedule is published. Changes to the schedule including notification of the test manager are the responsibility of the Schedules office. If an event does not occur due to unforeseen factors (such as foul weather or mechanical failure), the test manager applies the Test Management Cancellation policy for an equitable allocation of costs between the customer and the Range Department.”

3. Proposed Changes to the Instrumentation Design Process

In order for the relaxation of requirements for TSPI precision to have an impact on reducing restricted range times, the flow-down of relaxed requirements must translate to an improved instrumentation solution (i.e., one requiring less overall setup time). If the relaxation allows GPS or radar systems to meet the test objectives in place of KTM systems, then progress has been made.

There is potential for improvement beyond this step but significant cultural norms make such advances difficult to implement. The Instrumentation Division, like other range support groups, is dedicated to quality service and takes pride in a job well done. Getting the absolute best results on every test is ingrained in the China Lake culture and in the individuals who work here. As with many systems there are competing parameters. The closer to the test item the KTM is placed, the greater the TSPI precision

and the “wow” value from the product, but the less likely the placement can be used on the next event. The current culture is dominated by the desire to get the instrumentation systems as close to the event as possible in order to obtain the best possible product.

E. APPLICATION OF PROCESS CHANGES ON SELECTED TEST MONTH TO IDENTIFY IMPACT OF PROPOSED CHANGES

In this section the proposed process changes are applied to the selected baseline timeframe and the scheduling process is repeated. The results of this scheduling are compared with the results of the original scheduling to provide the MOE.

1. Changed Process Simulation

Scheduling requires a large amount of real-time interaction between schedulers, test managers, customers, and resource providers. There are two full-time schedulers who work to find an efficient allocation of resources. Scheduling conflicts are avoided when programs are flexible in one or more of three areas. First is the ability to test at a different time on the same day. The second is the ability to move a test to another day. The third is the ability to utilize a different range location for the test.

It is not possible to re-create the exact conditions that existed a year in the past, nor is it possible to allocate weeks of time from the vast cast of characters that contributed to the original scheduling process. **The scheduling office personnel performed the actual scheduling using the new processes in a manual simulation.** The same paper schedule requests used in the original scheduling from baseline dates were used as the input. Simulation of scheduling activities for a period of time in the past presented a few challenges. Simulation is only possible when the flexibility of the various customers can be considered. To allow the considerations of flexibility within the simulation, test managers familiar with the programs provided ratings of flexibility for their customers who requested time on the schedule in the months of July to September 2007. Rating values and the applicable rules are shown in Table 4. Only one in four events with moderately flexible ratings were allowed to flex for scheduling purposes. These tests allowed to flex were selected at random prior to the simulation.

Area of flexibility	Rating	Rule for Simulation
Time of Day	1 - Very Flexible	Can move the event to another time on the same day within the normal constraints of scheduling
	2 - Moderately Flexible	One in four events with this rating can be moved within the normal constraints of scheduling
	3 - Not Flexible	The time for this event is a hard requirement
Day of the Week	1 - Very Flexible	Can move the event to another day of the same week within the normal constraints of scheduling
	2 - Moderately Flexible	One in four events with this rating can be moved within the normal constraints of scheduling
	3 - Not Flexible	The day for this event is a hard requirement
Location of the Test	1 - Very Flexible	Can move the event to another suitable location on range
	2 - Moderately Flexible	One in four events with this rating can be moved within the normal constraints of scheduling
	3 - Not Flexible	The location for this event is a hard requirement

Table 4. Customer flexibility rating assigned by test managers and the resulting rule to be used in the simulation.

2. Results of Simulation

The 18 days involved in the rescheduling simulation included 11 work days. China Lake is on a schedule that provides every other Friday as a day off. August 13 was a safety stand-down day. As required, the scheduling under the proposed procedures ensured that all previously scheduled tests were placed on the schedule. The daily effect of the process is shown in Figure 9. There was a compressive effect in the new process that was anticipated. **This compression better utilized days early in the week, creating larger blocks of available time at the end.** Larger blocks of free time are much more useful in scheduling additional tests than are smaller time periods. The application of process changes resulted in eight additional free range hours that could be used for testing. The process also reduced the need for overtime flights in the same period by four hours.

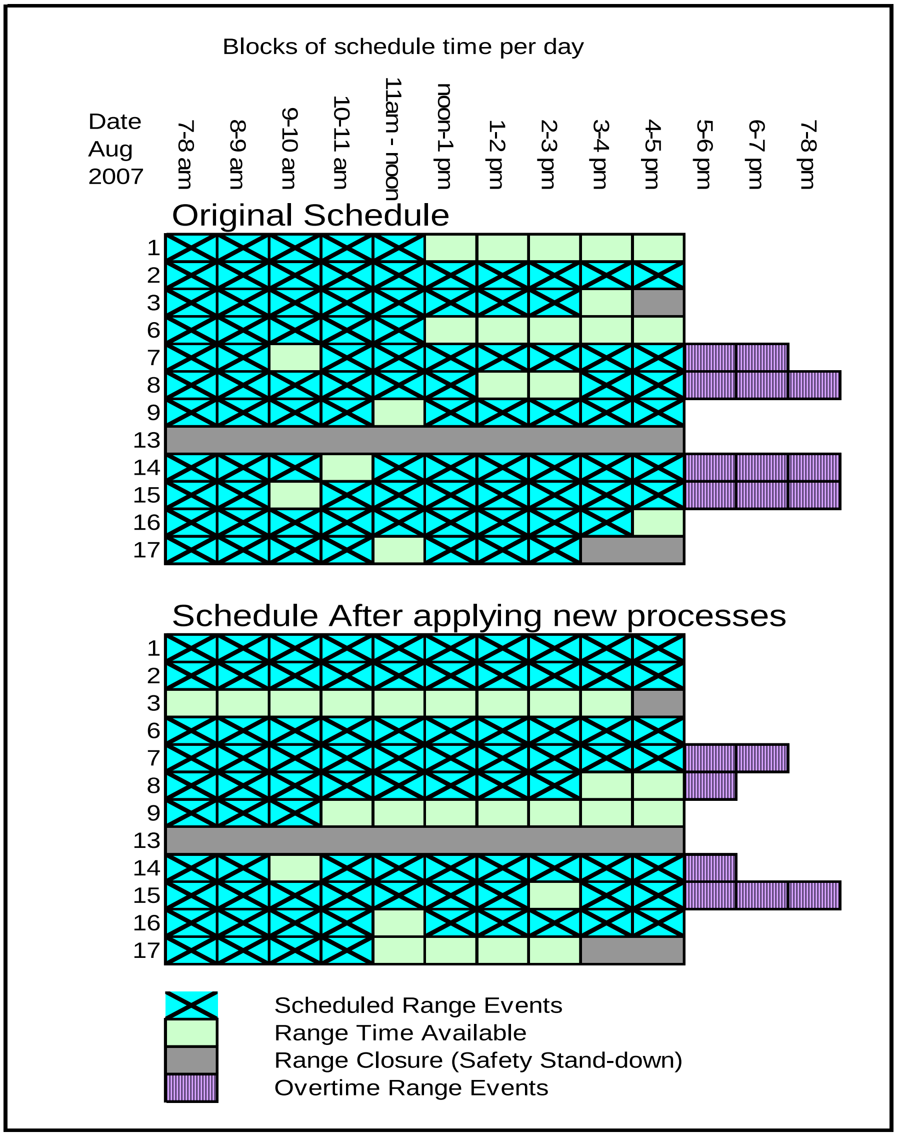

Figure 9. Impact of the new processes on the range schedule.
The new process utilizes unused time slots earlier in the week and frees up larger blocks of time for later.

The eight hours reclaimed by the new process represent nearly 9% of the schedulable time. This time can be used for additional testing. The exact amount of testing that could be fit into the reclaimed hours depends on the details of the tests. One large test event with complex instrumentation requirements could take nearly the entire time, or many less intensive tests could share the airspace and other resources. Based on the average time for tests in the baseline time period, an additional six test events could be conducted in the eight hours provided.

In the event that no additional tests are requested, training, maintenance, calibrations, and other needed range activities can be accomplished. The larger blocks of available time are more useful for these activities than the equivalent amount of time in smaller blocks.

3. Discussion of Results

This manual simulation is susceptible to errors as are all simulations. Not all proposed process changes could be sufficiently simulated. The requirements definition process changes must be applied to actual customers and would involve lengthy and detailed analyses involving many customers and their supporting analysts in the initial planning phase. If the recommendations in this thesis are implemented, the weekly scheduling task would begin with some tests firmly scheduled through the advance scheduling process. To prevent an overly optimistic outcome, the rules of the simulation limited the maximum flexibility of a test to another time slot in the same week. This restriction will not exist when the proposed processes are implemented.

There were known weaknesses in the simulation. Resource setup times were not recorded from the actual events, but estimated by the providers after the fact. A simulation of this advanced scheduling on the first week was not performed due to difficulty in simulating the process change in the forecasting meeting a year after the fact. The flexibility ratings assigned by the test managers were estimations. In retrospect, it is possible that the simulation rules for tests that were "very flexible" should have included a restriction as did those for "moderately flexible." If the simulation were run again, the suggestion would be to only allow half of the "very flexible" tests to be moved.

Additional insights and a more accurate representation of the impacts of the process changes could be determined with a simulation that considered a longer period of time. A longer simulation would show the impact of the sliding window effect after a few weeks. The time demands on the scheduling office prevent repeating or extending the simulation. Using persons other than the schedulers to perform further simulation would lack an element of realism needed to give credibility to the results.

Restrictions on flexibility would likely reduce the benefit, while implementing advanced scheduling and a longer simulation would increase the benefit. The potential for skewing the simulation with these inconsistencies was discussed with the participants before and after the simulation. All participants agreed the simulation had weaknesses, but that the potential for improvement shown in the results was valid.

F. CHAPTER SUMMARY

The after-the-fact scheduling simulation was not a perfect representation of the process but rules were applied to make it a reasonable representation. The resulting data show strong potential for improved throughput if the proposed process changes are implemented.

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V. CONCLUSIONS

A. KEY POINTS AND RECOMMENDATIONS

Application of the proposed process changes to historical data gives a strong indication of the potential for improved throughput. The process changes proposed in this paper are recommended for implementation. It will take time for the proposed processes changes to take hold with the range employees and with customers. Management will need to follow through to ensure the improved processes are implemented and followed.

B. AREAS TO CONDUCT FURTHER RESEARCH

The process of collecting the data, interviewing employees, and analyzing processes illuminated other areas that would potentially benefit from further study. The Range Department currently supports a strong continuous process improvement (CPI) program with personnel trained in the use of many tools. It is hoped that some of the suggestions below could become efforts of the CPI program.

1. Selection of Best Target Locations and Optimum Number of Targets

Target locations on the ranges have been designated by testers over the past 65 years. Many target locations have low value because of the poor line of sight to current instrumentation sites, or are located a long distance from good roads. Many of these poor locations continue to be used. There are hundreds of surveyed target locations on the range. Further study is recommended to:

- Determine the number of target locations needed to efficiently meet the needs of the range customers.
- Identify the best target locations based on customer needs and on range supportability.
- Provide documentation of the resulting targets and locations for use by test management in communicating target options to the customers.

2. Improve Rigor in Test Design Including Better Access to Common Support Tools

Interviews highlighted the fact that more scientific rigor should be applied to test design. It was also noted that some range personnel had not been aware of tools that could assist them in the design of instrumentation setup. An example of such an instance is the selection of KTM placement sites without the aid of mapping tools such as shadow graphs. An assessment of the test design processes on the ranges would be a large undertaking but could provide significant insights into areas that need improvement.

3. Culture Change to Allow More Efficient Instrumentation Setup

Significant benefits from relaxed precision requirements will only be possible when the desire of instrumentation personnel is to find the maximum distance from target that their systems can be located and still meet customer requirements. In such an environment one could realize additional benefits through an increase in the number of instrumentation setups that meet multiple test event requirements. The previous recommendation will need to be fully implemented before this one is worth addressing.

4. Development of Permanently Instrumented Test Sites

The impact of instrumentation resources required for setup on Baker Range (a sub-division of the Land Range) was noticeable by its lack of impact on range setup time. This is because Baker Range has a permanently installed camera scoring system. If the results of the target location study suggested in part 1 show a location or locations that could be used by many tests, then the sites should also be studied for the feasibility and benefits of permanent instrumentation.

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